Learning from Extreme Events: Risk Perceptions after the Flood

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ABSTRACT. *This paper examines whether a severe flood causes homeowners to update their assessment of flood risk as seen in a change in the price of floodplain property. I use data on all single-family, residential property sales in St. Louis County, Missouri, between 1979 and 2006 in a repeat-sales model and a property fixed-effects model. After the 1993 flood on the Missouri and Mississippi rivers, property prices in 100-year floodplains did not change significantly, but prices in 500-year floodplains declined by between 2% and 5%. All property prices in municipalities located on the rivers fell postflood by 6% to 10%.* (JEL Q51, Q54)

I. INTRODUCTION

The costs of natural disasters, both worldwide and in the United States, have grown dramatically in recent years (Kunreuther and Rose 2004; Cutter and Emrich 2005; Munich Re 2005). Damages from flood events are of particular concern: in the United States during the twentieth century, floods accounted for more lives lost and more property damage than any other natural disaster (Perry 2000). Much of the rise in disaster-related costs can be explained by increased value in hazardous areas (Kunreuther and Michel-Kerjan 2007). Both people and capital have been moving into floodplains (e.g., Montz and Gruntfest 1986; IRC-IIPLR 1995; Hipple, Drazkowski, and Thorsell 2005), driving up costs when a flood occurs. This raises questions regarding the information homeowners have about flood risk and how they perceive the risk.

In 1993, one of the worst floods in U.S. history engulfed the Midwest as the Missouri and Mississippi rivers rose to record heights. The National Oceanic and Atmospheric Administration (NOAA) estimates that 20 million acres in nine states were flooded. Damage estimates of quantifiable impacts range from $12 to $20 billion (IFMRC 1994; U.S. General Accounting Office 1995; Galloway 2005).[1] St. Louis County, Missouri, lies just below the confluence of the two rivers and was dramatically affected by the flood, making it a natural case study. The flood damaged 1,678 residential properties in the county (U.S. Army Corps of Engineers, Mississippi Valley Division 2000), as well as roads, businesses, and public facilities, imposing costs on all members of the affected communities.

This paper is one component of a larger investigation regarding what we can, should, and do learn—as individuals and as a society—about the probability and severity of natural disasters from the occurrence of an extreme event. I focus here specifically on St. Louis County, asking what homeowners did learn from the 1993 flood and using the capitalization of flood risk into property prices to gauge homeowners' perceptions of flood risk. I ask three specific questions in the paper.

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[1] For comparison, Hurricane Andrew, the record-setting event before Katrina, caused a little over $20 billion in estimated damages, and Hurricane Katrina dwarfed both of these disasters with estimated damages close to $125 billion.

First, did homeowners in St. Louis County have some knowledge of flood risk *before* the occurrence of the 1993 flood? Second, did the 1993 flood alter perceptions of flood risk? And third, did changes in perceived risk vary spatially across the county and temporally in the years after the flood? The answer to this latter question is the main contribution of this paper.

The issue of learning from extreme events is particularly worth exploring when experts disagree about the magnitude of the risk and/or when the risk is changing over time; in such cases, it is not always clear what is and should be inferred from the occurrence of a disaster. These two conditions characterize flood risk in St. Louis County. Following the 1993 flood, experts estimated that a flood of that magnitude could be expected in St. Louis on average once every 50 years (Criss and Shock 2001), once in slightly more than 100 years (Parrett, Melcher, and James 1993), or once every 200 to 500 years.[2] In addition, flood risk in St. Louis County has increased over time due to expanded urban and suburban development, which increases run-off by reducing infiltration (Deyle et al. 1998), engineering works on the Missouri and Mississippi that have increased flood stages over time (e.g., Ehlmann and Criss 2006), and possibly climate change (Wuebbles and Hayhoe 2004).

To first determine how flood risk was capitalized into property prices before the flood, I use a hedonic property model (Rosen 1974; Freeman 2003) to estimate the price difference between residential properties within and outside of the floodplain over the years 1979–1993 (until the flood). Previous studies have found a price discount for floodplain properties that, based on certain models of homeowners' decision making, can be interpreted as the amount homeowners must be compensated to take on the flood risk. I find that before the flood, properties in 100-year floodplains (those with a 1% chance of flooding in any given year or a 26% chance of flooding at least once during a 30-year mortgage) were discounted 3.2% to 3.9% compared with property outside of the floodplain. There was not a statistically significant discount for properties in 500-year floodplains (those with a 0.2% chance of flooding in any given year and a 6% chance of flooding at least once during a 30-year mortgage) before the flood. As home buyers are, under the National Flood Insurance Program (NFIP), supposed to be informed of the flood risk before purchasing property within 100-year floodplains but not 500-year floodplains, these findings suggest that the information provision aspect of the NFIP may be working.

To test whether the 1993 flood provided new information to homeowners about flood risk, I use a repeat-sales model and a property fixed-effects model (as well a difference-in-differences [DD] specification as a robustness check) to test whether the price differential between floodplain and nonfloodplain lands was altered after the flood. I find no statistically significant decline in prices for property in 100-year floodplains after the flood, but property prices in 500-year floodplains fell by between 2% and 5%. That is, where property prices already accounted for some knowledge of flood risk, little change in prices occurred. In areas previously exhibiting no flood risk discount, on the other hand, prices declined.

Finally, I examined whether learning from the flood varied across municipalities that border the Missouri River or the Mississippi River and those that do not. Municipalities located on one of these rivers sustained most of the flood-related damages, whereas municipalities in the county's interior experienced little or no flood damage. In municipalities that share a border with the Missouri River or the Mississippi River, all residential property—in or out of the floodplain—fell in price by 6% to 10.5%, on average, compared with property in the county's interior. After a flood, homeowners may not only update their assessments of the likelihood of a flood occurring, which would be zero for those outside floodplains, but also of the level of damage they suffer in the event of a

[2] This latter estimate is extrapolated from the NOAA web site: http://www.crh.noaa.gov/ahps2/.

flood. This finding thus could reflect homeowners recognizing that a flood imposes costs on all members of a community, even those not in floodplains. The result could also suggest that municipalities on the rivers were stigmatized by the flood; they could have been labeled as "risky" or "flood-prone," creating a drop in property prices even when parts of the community are not subject to flood risk. It is difficult to tease out year-by-year changes postflood from the data, but it appears that the effects of the flood diminish with time, although not rapidly.

II. HOMEOWNERS AND RISK: PREVIOUS RESEARCH

Previous studies have noted that natural disasters provide information on risk levels, yet few provide detailed analyses of these "information effects" (Yezer 2002). Given that disasters are low-probability events (so we rarely have a time series long enough to accurately estimate probabilities) and that many of the risks may be nonstationary, the occurrence of an event should cause an updating of subjective probabilities on the occurrence and/or magnitude of an event. In this paper, I follow others by using property prices to test empirically whether homeowners perceive a risk and how that perception changes in response to new information provided by a disaster.

A handful of papers examine the effect on housing prices of other adverse environmental events, such as a pipeline explosion (Hansen, Benson, and Hagen 2006), the Three Mile Island nuclear accident (Nelson 1981), the explosion of a chemical plant (Carroll et al. 1996), and the Loma Prieta earthquake (Beron et al. 1997). These studies, along with cross-sectional analyses of the impact of environmental (dis)amenities on property prices, show that, first, homeowners perceive many environmental risks and adjust their risk assessments following disasters, and, second, these perceptions can be inferred from property prices.

A fairly substantial literature estimates the effect of flood risk on property values, largely using cross-sectional data. These papers generally find a price reduction for property in the floodplain that is often larger than the present value of annual insurance premium payments (Schilling, Benjamin, and Sirmans 1985; MacDonald, Murdoch, and White 1987; Shilling, Sirmans, and Benjamin 1989; Holway and Burby 1990; MacDonald et al. 1990; Speyrer and Raga 1991; Harrison, Smersh, and Schwartz 2001; Bin and Polansky 2004; Bin and Kruse 2006; Bin, Kruse, and Landry 2008). Only three studies, however, investigate how a major flood event alters the price differential between property prices inside and outside of floodplains and, by extrapolation, how a disaster alters a homeowner's assessment of risk. First, Skantz and Strickland (1987) studied inland flood risk;[3] using a 1979 flood in Texas as a case study, the authors found no drop in property prices after the flood, but they did find a decline in prices from an increase in insurance costs a year later. Their sample size is small, however, with only 33 sales of flooded homes and a total sample size of 133. The two other papers examine the effect of hurricanes. Bin and Polansky (2004) used a DD approach, finding that the differential in price between properties inside and outside the floodplain in Pitt County, North Carolina, increased after Hurricane Floyd. Carbone, Hallstrom, and Smith (2006) used a repeat-sales model to estimate the new risk information conveyed by Hurricane Andrew to homeowners in one county that was directly hit and one that was a near miss. The authors found that property prices increased at a lesser rate posthurricane in both counties.[4]

The decline (or slower increase) in property prices immediately after a disaster is consistent with theories of how individuals evaluate low-probability events. Due to

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[3] One other paper examines the effect of an inland flood on property values, but it does not use regression analysis; it only compares summary statistics of sale prices and examines more descriptive data (Tobin and Montz 1988).

[4] This 2006 paper builds on a very similar paper that examines only the "near-miss" county (Hallstrom and Smith 2005).

cognitive limitations, or bounded rationality (Simon 1957), individuals cannot evaluate all the risks they face; instead, they adopt ways to simplify their decision making. Individuals often neglect low-probability events (Kahneman and Tversky 1979; Kunreuther et al. 2002), but a major disaster can have an attention-focusing effect, increasing perceived risk (Hansen, Benson, and Hagen 2006). This can be explained by the availability heuristic, through which individuals assess the probability of an event's occurrence by how easily examples of such events come to mind (Tversky and Kahneman 1973). Individuals may also simplify their decision making by paying attention only to risks that they assess to be greater than a subjective threshold (Camerer and Kunreuther 1989). A disaster of sufficiently large magnitude could cause a risk to be assessed as greater than the threshold when previously it was not. Individuals also often demonstrate an optimistic bias toward disasters, thinking, "It can't happen to me" (Camerer and Kunreuther 1989). Once it does happen to them, individuals may update their risk assessments.

The finding of an increase in perceived risk after a disaster may or may not apply to inland flooding, however, or specifically to St. Louis County, for three reasons. First, inland flood events are usually referred to by experts and the press as an x-year event, such as a 100-year flood. Some individuals misinterpret this language to mean that once a 100-year flood has occurred, they are safe for another 100 years; instead, it means that each year, there is a 1% chance that a flood of that magnitude will occur (Pielke 1999). This is essentially the gambler's fallacy, or the belief that the likelihood of an outcome falls just after it has occurred. This was the case for some residents of St. Louis County, such as one man who was quoted as saying, "This won't happen again for another 100 years" (Best and Linsalata 1993). If homeowners hold this belief, we will not see property prices fall after a major flood event because homeowners would mistakenly assume that they are now safer. That said, it does seem unlikely that enough homeowners would misunderstand the terminology in this way to cause an observable effect on prices.

Second, flood insurance is available through the government, and rates did not increase after 1993. Therefore, even if a property owner believed that the risk of flooding had increased, this may not have caused an increase in property prices since the homeowner could have transferred the increased risk. Actually, of course, a disaster has many uninsurable costs, such as economic disruption or emotional hardship, and a realization that these costs are large could lower property prices. Further, very few homeowners in St. Louis County actually purchase flood insurance.

Finally, after the 1993 flood, an enormous amount of new construction was undertaken in the floodplains of St. Louis County. Although new development occurred in floodplains throughout the Midwest in the decade following the flood, Missouri—and St. Louis County in particular—has been a leader in floodplain development (Pinter 2005). Further, half of the St. Louis County floodplain development has been in floodplains that were inundated in 1993; in other states, no more than a quarter of new development has been in floodplains that were flooded in 1993 (Hipple, Drazkowski, and Thorsell 2005). This boom in floodplain development suggests that property owners in St. Louis County may not have increased their subjective risk assessment after the 1993 flood. It is important to note, however, that the majority of this new construction was nonresidential, so it may not be indicative of residential perceptions of flood risk. Also, because it was not homes, the supply of housing in and out of the floodplain did not change differentially postflood.

This paper contributes in three ways to the literature on the information effects of disasters. First and most simply, I further examine what homeowners learn from an extreme flood. Since almost two-thirds of the direct damages from natural disasters can be attributed to floods and hurricanes (van der Vink et al. 1998), flooding is a case study worthy of particular attention. Second, I estimate the information effect of inland flooding, a risk that has been somewhat neglected, with a large, comprehensive dataset of over 430,000 residential property sales. Finally, the dataset compiled for this paper allows for an investigation of spatial heterogeneity in the information effect of the flood. I estimate not only the information effect across 100-year floodplains, 500-year floodplains, and non-floodplain land, but also the differences between municipalities that border the Missouri River or the Mississippi River and those that do not. Year by year changes postflood are also examined.

III. AT THE CONFLUENCE: BACKGROUND ON ST. LOUIS COUNTY, MISSOURI

Flood Risk in St. Louis County

Located at the confluence of the Missouri and Mississippi rivers, flooding has always been a concern for St. Louis City and County residents. Figure 1 maps the major rivers and floodplains in St. Louis County.[5] The Missouri River runs along the north of the county, merging with the Mississippi River in the northeast corner of the map and then flowing south. Some of the numerous streams and creeks throughout the county are visible on the map. They also have associated floodplains. Figure 2 is a close-up map showing residential property boundaries and a creek in the county's interior with its surrounding floodplain.

In 1993, flooding on both the Missouri and Mississippi rivers threatened St. Louis County. Throughout the month of July, rivers remained above flood stage because of summer storms following an unusually wet spring. Many 100-year and 500-year floodplains were inundated. Tributary streams and creeks backed up, notably the River des Peres in the south of the county, and several levees throughout the county failed, damaging homes and businesses. Most of the damage was sustained along the edge of the county, near the major rivers. Unfortunately, to my knowledge, no data are available on the extent or amount of flood damage at a parcel level for St. Louis County. Available information indicates that around 250 homes were flooded out, and some portion of these could not rebuilt; overall, 1,678 homes sustained some damage (Schlinkmann 1993; U.S. Army Corps of Engineers, Mississippi Valley Division 2000). For reference, there are over 220,000 residential properties in the county, so less than 1% were damaged. While it is possible a major flood could alter sale rates in and out of the floodplain, the number of properties selling in floodplains did not increase disproportionately immediately after the flood (Figure 3). Flood damage to infrastructure and businesses led to broader disruption in the community. A portion of a major east-west highway in the county was flooded and closed (Bower 1993). Four bridges were shut down, two water plants were closed, and a sewage treatment plant flooded, releasing raw sewage (*St. Louis Post-Dispatch* 1993). Seven hundred eighty-two commercial establishments were damaged—more than in any other city or county in the U.S. Army Corps of Engineers St. Louis District[6] (U.S. Army Corps of Engineers, Mississippi Valley Division 2000). In the larger St. Louis region, 1 out of every 111 workers was out of work for one or more days because of the flood (*St. Louis Post-Dispatch* 1993).

Most floods on the Missouri and Mississippi rivers are slow events: the flood crest is forecasted days in advance, giving communities time to evacuate if necessary. These rivers carry enormous volumes of water, and if a levee fails or is overtopped, the floodplain can be buried in many feet of water. During these large floods, the smaller tributaries, or streams, in St. Louis County may back up as well. The smaller streams

[5] The area covered by the north arrow on the right side of the map is St. Louis City, which I do not examine in this paper.

[6] The St. Louis district includes more of Missouri than St. Louis, and it also includes parts of Illinois.

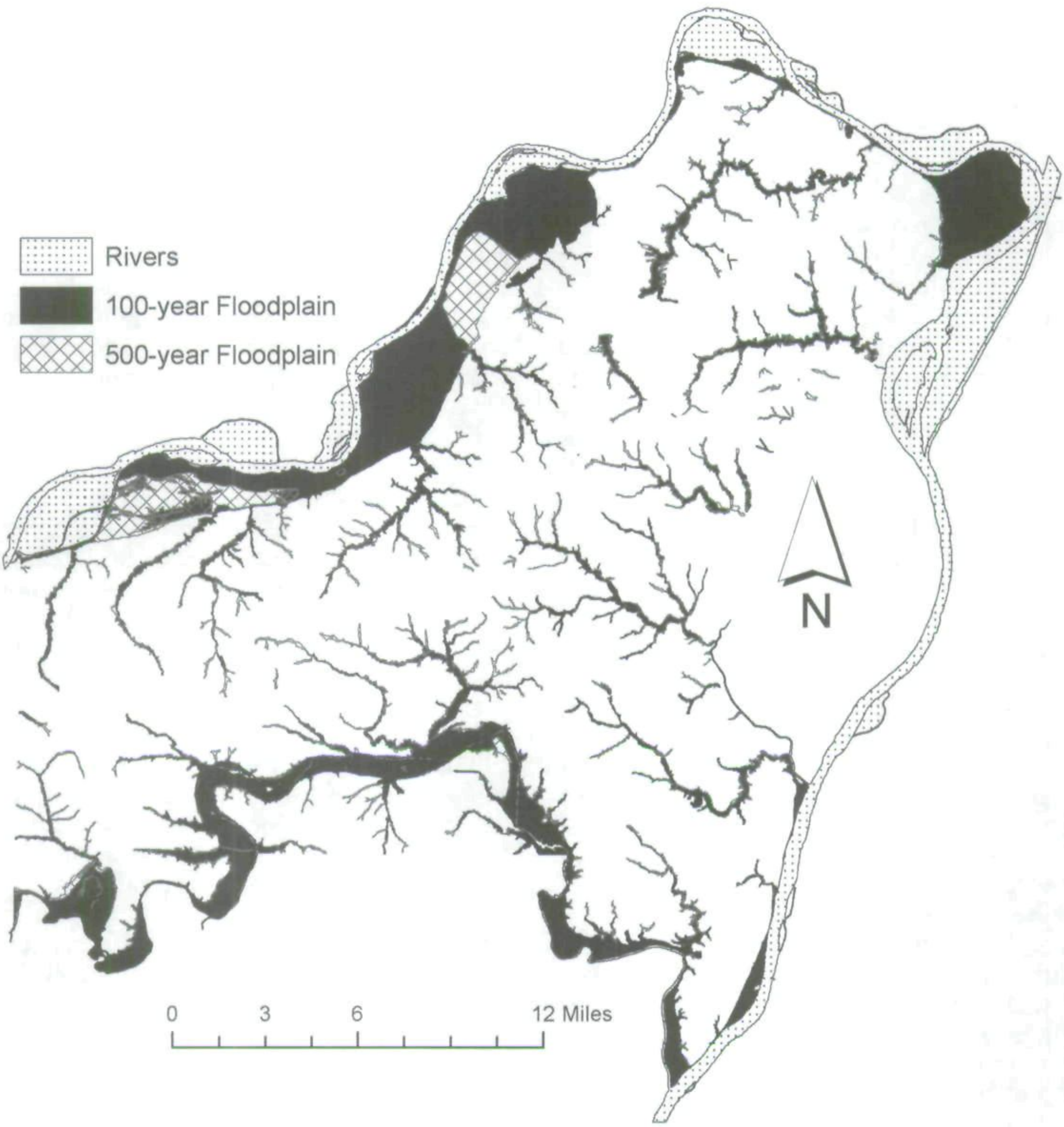

FIGURE 1
RIVERS AND FEDERAL EMERGENCY MANAGEMENT AGENCY–DESIGNATED FLOODPLAINS IN ST. LOUIS COUNTY

are also prone to flash flooding from heavy rainfall that would not impact the large rivers. The risks along the major rivers and the tributaries are thus qualitatively different, and although the 100-year or 500-year floodplain categorization by the Federal Emergency Management Agency (FEMA) does not differentiate among these types of risk, homeowners might.

The National Flood Insurance Program

Flood insurance for homeowners is available through the National Flood Insurance Program (NFIP), a FEMA-managed program enacted in 1968 partly in response to the lack of availability of private flood insurance. To determine a household's risk, and therefore premiums,

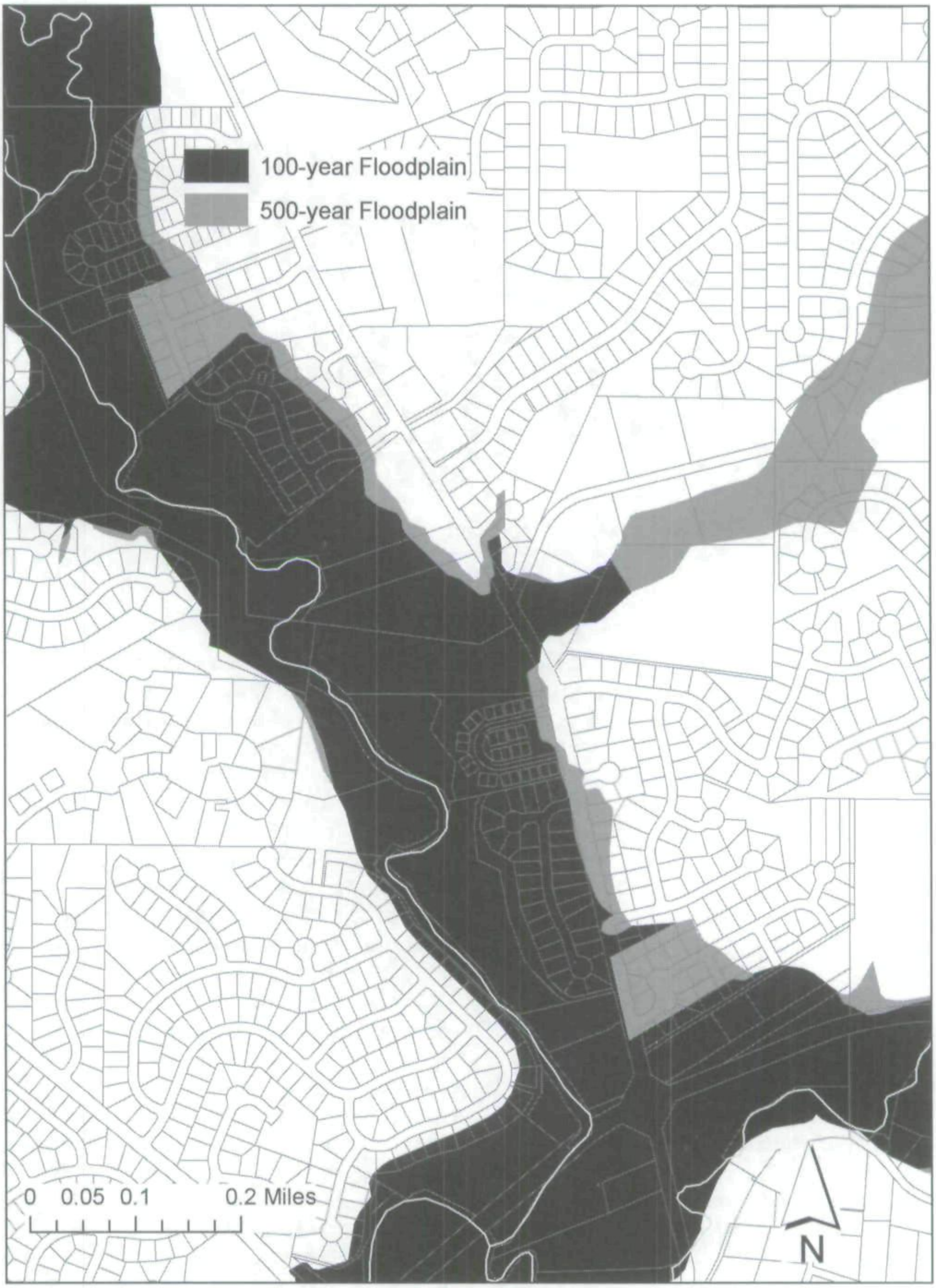

FIGURE 2
FLOODPLAINS IN THE INTERIOR OF THE COUNTY

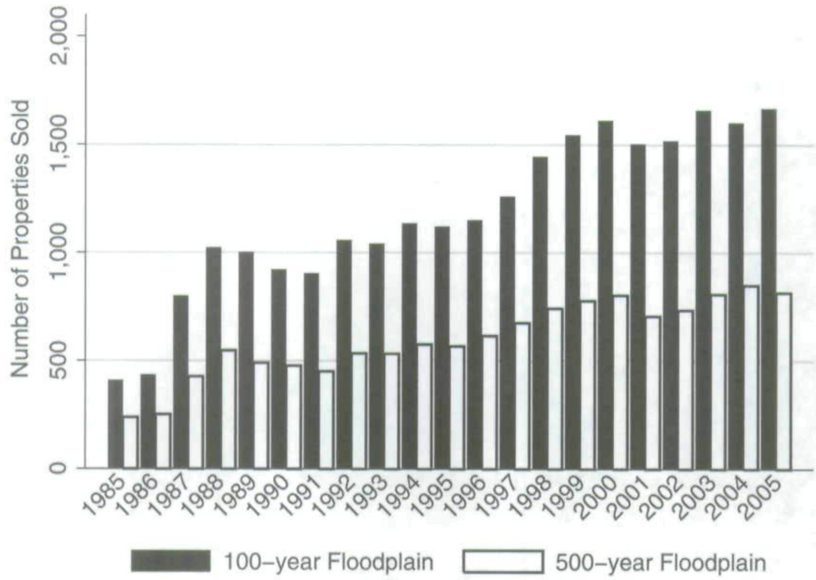

FIGURE 3
Number of Properties Sold by Year

FEMA maps 100-year and 500-year floodplains in participating communities.[7] In 1973, low take-up rates prompted Congress to mandate flood insurance for properties in 100-year floodplains with a mortgage from a federally backed or regulated lender. Despite this, take-up rates remain quite low. In the Midwest, take-up rates in 100-year floodplains have been estimated at around 20% (Dixon et al. 2006).[8]

If the mandatory purchase requirement is operating correctly, home buyers should be informed before purchasing a property if it is located within a 100-year floodplain. However, one study found that in Boulder, Colorado, a majority of home buyers did not know of the flood risk or the cost of flood insurance until the time of closing or later (Chivers and Flores 2002). If such ignorance was widespread in St. Louis County before the 1993 flood, when negotiating a sale price many property owners in 100-year floodplains may have been unaware that their properties were at risk of flooding. There are no NFIP mechanisms to alert purchasers of property outside of 100-year floodplains of any flood risk they might face. It is also important to note that FEMA maps may not be accurate reflections of the risk. Around 75% of FEMA maps are over a decade old and are not updated frequently enough to incorporate increased development, new data, or new estimation techniques (FEMA, Federal Insurance and Mitigation Division 2002). It is unclear how much homeowners rely on or trust FEMA designations.

As a result of privacy regulations, the federal government will not release the addresses of homeowners who have purchased insurance, so it is not possible to control for insurance at a property level in the empirical analysis. Aggregate statistics indicate, however, that very few homeowners in St. Louis County had flood insurance around the time of the flood. In 1992, there were only 4,032 policies in force in St. Louis County out of more than 220,000 residential properties in the county, with approximately 14,000 residential properties within 100-year floodplains, and nearly half as many within 500-year floodplains. At the end of the year in 1993, this number had jumped to 5,652. It has since

[7] The 100-year and 500-year floodplains are two distinct areas with no overlap.

[8] For more details on the NFIP, see Pasterick (1998).

fallen; in 2007 there were 5,488 policies in force.[9] Much of the increase in insured properties between 1992 and 1993 was due to property owners buying coverage in the days before the flood crest reached St. Louis. In 1993, flood insurance took effect within a few days of purchase, so homeowners were able to forgo years of premium payments, buy a policy right before the flood, and then file a claim days later. This loophole was closed in 1994; now flood insurance takes effect only after a 30-day waiting period. Since fewer than 2% of properties had insurance at the time of the flood, and the percentage of households with insurance was never greater than 2.5% between 1993 and 2006,[10] it is unlikely that the cost of insurance drives property prices in St. Louis County.[11]

Even if take-up rates are very low, the discounted present value of flood insurance plus the cost of any uninsurable damages[12] should be a bound on the price discount associated with floodplain properties. Changes in insurance prices could thus be expected to alter property prices. NFIP rates, however, did not change following the 1993 flood. The NFIP can raise rates only once a year, in May. By law, any yearly increase in premiums cannot exceed 10% averaged across all flood zones. Rates are set for the nation as a whole by examining the loss ratios of different flood zones and are not location specific. They are, therefore, not changed in response to any one event in the country and cannot be differentially changed for certain counties, states, or regions.[13] The 1993 flood was probably not a large enough event to have dramatically altered loss ratios because so many homeowners in the Midwest were uninsured.

The NFIP's 100-year and 500-year floodplain designations suggest that the risk changes abruptly at the boundary of the 100-year floodplain. In reality, flood risk changes continuously across the landscape. Most papers examining the effect of flood risks on housing prices use the FEMA-designated floodplains as a proxy for flood risk. Flood risk can be more precisely estimated, as was done by Bartošová et al. (1999), by using geographic information systems (GIS) to model flooding and assign a unique value of flood risk to each property. Homeowners would almost never have such detailed knowledge regarding flood risks, however, making such fine-grained risk differentiation unlikely to be capitalized into housing prices. Homeowners in St. Louis County may perceive, though, a difference in risk between living on a small creek versus the banks of a larger river. Thus, in this paper, I test for a spatial difference in the information effect of the 1993 flood between properties in the interior of the county versus those on the Missouri River or the Mississippi River, but I do not develop a unique risk estimate for each property.

IV. MODEL

Following hedonic property models (Rosen 1974; Freeman 2003), the price of property is modeled as a function of neighborhood characteristics (such as school district), $\mathbf{Z_N}$, locational characteristics (e.g., distance to highways or parks), $\mathbf{Z_L}$, structural characteristics (e.g., size of

[9] Thanks to Tim Scoville for providing me with this data.

[10] It is not possible to determine the percentage of properties in 100-year floodplains that had insurance because the NFIP data gathered for this paper do not provide property addresses or flood zones.

[11] As seen in the above numbers for St. Louis County, the 1993 flood revealed alarmingly low take-up rates for flood insurance across the Midwest. In 1994, the Flood Insurance Reform Act was passed, with many of its provisions aimed at increasing compliance with the mandatory purchase requirement. Although this act passed in the year following the 1993 floods, it should not confound the results of this paper because most financial institutions did not become subject to this new regulation until well into 1996. Even now, debate continues as to how extensively the regulation is enforced, and the aggregate data for flood insurance purchases in St. Louis County do not show a dramatic increase following passage or implementation of the act.

[12] This would include inconvenience costs, pain and suffering, below-deductible costs, and costs incurred above coverage levels. I am not considering the risk of death. Warning systems have dramatically reduced deaths.

[13] Thanks to Ed Pasterick for information on NFIP rate-setting policies.

the house or number of stories), $\mathbf{Z}_S$, and an environmental variable of interest—in this paper, a homeowner's subjective assessment of flood risk, denoted by the probability of a flood, p. Note that this is not an objective probability but the homeowner's perception of the probability. Characteristics that produce benefits, such as a larger home, increase the price of property, and characteristics that impose costs, such as a neighborhood with a high crime rate, reduce the price of property.

The model developed here builds on previous studies of risk and property prices (MacDonald, Murdoch, and White 1987; Gayer, Hamilton, and Viscusi 2000; Hallstrom and Smith 2005; Carbone, Hallstrom, and Smith 2006). Property owners maximize their utility subject to their budget constraints. Given Y as total income; X as a numeraire good, whose price is set equal to 1; $H()$ as the hedonic price function; and $\mathbf{Z}$ as the combined vector of the neighborhood, locational, and structural characteristics of the home, the budget constraint is given by

$$Y = X + H(\mathbf{Z}, p). \quad [1]$$

The homeowner's decision is modeled using a state-dependent utility function to allow for variation in the marginal utility of income across states, with NF denoting the case of no flood and F denoting the case of a flood.[14] Expected utility is, therefore, given by the equation

$$EU = pU_{\mathrm{F}}(X_{\mathrm{F}}, \mathbf{Z}) + (1-p)U_{\mathrm{NF}}(X_{\mathrm{NF}}, \mathbf{Z}). \quad [2]$$

If no flood occurs, X_{NF} equals total income, Y, minus the amount spent on housing, H. If a flood occurs, X_{F} is equal to $Y - H - L$, where L is the losses sustained from a flood. Maximizing expected utility subject to the homeowner's budget constraint gives

$$\frac{\partial H}{\partial p} = \frac{U_{\mathrm{F}} - U_{\mathrm{NF}}}{p\frac{\partial U_{\mathrm{F}}}{\partial X} + (1-p)\frac{\partial U_{\mathrm{NF}}}{\partial X}}. \quad [3]$$

[14] While a devastating flood does not necessarily lead to a change in the marginal utility of income, it is possible that this could occur.

Equation [3] is the expression for the implicit price of risk. It is the coefficient on the risk variable estimated in the hedonic regressions. In theory, this implicit price can be used to estimate welfare effects, or the willingness to pay, of marginal changes in the independent variable.[15]

Previous similar models have referred to the compensation a homeowner requires to take on additional risk as a risk premium or an option price (MacDonald, Murdoch, and White 1987; Carbone, Hallstrom, and Smith 2006). The empirical analysis here actually estimates the discount on the price of property needed to compensate the homeowner for higher risk levels. I model this risk discount explicitly as one element of the price of property. The amount of the risk discount (RD) can be defined as the decrease in the price of the property a homeowner requires to take on some additional perceived risk (σ), such that the homeowner is indifferent between taking on the perceived risk and receiving the discount in price and not moving into the risky location. The following equation thus defines the risk discount:

$$\begin{aligned}&(p+\sigma)U_{\mathrm{F}}\{Y - H[\mathbf{Z}, RD(\sigma)] - L, \mathbf{Z}\} +\\&(1-p-\sigma)U_{\mathrm{F}}\{Y - H[\mathbf{Z}, RD(\sigma)], \mathbf{Z}\}\\&\quad = pU_{\mathrm{F}}[Y - H(\mathbf{Z}, p) - L, \mathbf{Z}]\\&\qquad + (1-p)U_{\mathrm{NF}}[Y - H(p, \mathbf{Z}), \mathbf{Z}]. \quad [4]\end{aligned}$$

Expected utility with the slight increase in risk and the associated risk discount is

$$\begin{aligned}EU = &(p+\sigma)U_{\mathrm{F}}\{Y - H[\mathbf{Z}, RD(\sigma)] - L, \mathbf{Z}\}\\&+ (1-p-\sigma)U_{\mathrm{NF}}\{Y - H[\mathbf{Z}, RD(\sigma)], \mathbf{Z}\}. \quad [5]\end{aligned}$$

Maximizing this expression subject to the

[15] Note that only if buyers are identical will the hedonic price function identify a demand curve (Rosen 1974). A hedonic analysis also makes many assumptions: that the market is in equilibrium, that moving costs are negligible, and that the data captures one housing market. It seems highly plausible that St. Louis County could be considered one housing market. Moving costs are clearly positive, and so households will not move unless the utility gain from doing so is greater than the costs. This will create divergence between the estimated implicit price and true marginal willingness to pay (Freeman 2003).

change in risk σ, and solving for the change in the RD a homeowner requires for a change in σ gives

$$\frac{\partial RD}{\partial \sigma} = \frac{U_F - U_{NF}}{(p+\sigma)\frac{\partial U_F}{\partial X} + (1-p-\sigma)\frac{\partial U_{NF}}{\partial X}}. \qquad [6]$$

The right-hand side of equation [6] is the same expression as in equation [4], which gave the implicit price of risk for the case of $\sigma = 0$; this, as MacDonald, Murdoch, and White (1987) note, is the first increment to changing p. Thus, the partial derivative of the hedonic price equation with respect to the risk variable gives the change in the property price discount required for an increase in risk. This justifies interpreting the coefficients in the hedonic regressions as estimates of the amount of compensation a homeowner requires, through a lower property price, to move into a riskier area.

In the empirical analysis, location—whether the property is located within the 100-year or 500-year floodplain—must be used as a proxy for flood risk. As I show below, this makes it difficult to isolate the implicit price of risk. Location clearly alters the probability of a flood occurring; it is higher for 500-year floodplains than non-floodplain lands and higher still for 100-year floodplains. So the subjective probability of a flood, p, is a function of location, denoted here by $p(\ell)$. Location, however, also alters the loss (direct and indirect) a property owner faces independently of how losses change as a result of a change in probability. For example, consider two properties outside of the floodplain, both with a zero probability of flooding. If one has an access road that goes through the floodplain, that homeowner will still face losses in a flood, even though the probability of the property flooding is zero. So losses, as well as probability, are a function of location. Finally, location also enters the utility function of a homeowner directly because location carries with it amenities or disamenties. For example, in coastal regions, there is clearly concern that a variable identifying properties on the beach would serve as a proxy both for hurricane risk and for amenities, such as a view of the ocean. For this reason, a floodplain discount may not be found for coastal properties or floodplains associated with wave action unless amenities are controlled for (Bin and Kruse 2006; Bin, Kruse, and Landry 2008). This concern is less applicable to St. Louis County than for coastal areas, as the rivers and tributaries are not considered to be significant property amenities—as one homeowner said, the Missouri River floodplain is a "mosquito infested swamp." That is, although locating on the coast is an amenity risk (Kousky, Luttmer, and Zeckhauser 2006), locating on the river may be decidedly less so. In that case, however, it is the disamenties of location that must be considered.

It is not possible to isolate the implicit price of risk when location impacts losses and utility as well as the probability of a flood. To see this, following Carbone, Hallstrom, and Smith (2006), probability, losses, and utility are all now modeled to be a function of location, ℓ:

$$\begin{aligned} EU = {} & p(\ell)U_F\{Y - H[p(\ell), \mathbf{Z}] - L(\ell), \mathbf{Z}, \ell\} \\ & + [1-p(\ell)]U_{NF}\{Y - H[p(\ell), \mathbf{Z}], \mathbf{Z}, \ell\}. \qquad [7] \end{aligned}$$

Maximizing this expression gives

$$\begin{aligned} \frac{\partial H}{\partial \ell} = {} & \frac{\frac{\partial p}{\partial \ell}(U_F - U_{NF})}{p\frac{\partial U_F}{\partial X} + (1-p)\frac{\partial U_{NF}}{\partial X}} - \frac{p\frac{\partial L}{\partial \ell}}{p\frac{\partial U_F}{\partial X} + (1-p)\frac{\partial U_{NF}}{\partial X}} \\ & + \frac{p\frac{\partial U_F}{\partial \ell} + (1-p)\frac{\partial U_{NF}}{\partial \ell}}{p\frac{\partial U_F}{\partial X} + (1-p)\frac{\partial U_{NF}}{\partial X}}. \qquad [8] \end{aligned}$$

Equation [8] shows that the impact of a change in location on housing prices is composed of three terms: the risk discount, or implicit price of risk, multiplied by how a change in location alters the subjective probability of a flood; the effect of location on losses; and the effect of location on utility directly. When location is used as a proxy for the probability of a flood, these three terms cannot be distinguished. This motivates the many specifications undertaken in the first set of hedonic regressions to control for the effects of location on utility and losses.

Even when it is not possible to separate these effects, however, Carbone, Hallstrom, and Smith (2006) discuss how the risk discount can be identified with an exogenous event that provides new information to property owners. The 1993 flood is taken as one such event. The approach is quite similar to the Bayesian model presented by Gayer, Hamilton, and Viscusi (2000) in analyzing the effect of information about Superfund sites. The probability of a flood is now modeled as a function of information (I), making expected utility

$$EU = p(I,\ell)U_{\mathrm{F}}\{Y - H[p(I,\ell),\mathbf{Z},\ell] - L(\ell),\mathbf{Z}\} + [1 - p(I,\ell)]U_{\mathrm{NF}}\{Y - H[p(I,\ell),\mathbf{Z}],\mathbf{Z},\ell\}. \quad [9]$$

Maximizing expected utility again and solving for the partial derivative of the hedonic function with respect to the new information gives

$$\frac{\partial H}{\partial I} = \frac{\frac{\partial p}{\partial I}(U_{\mathrm{F}} - U_{\mathrm{NF}})}{p\frac{\partial U_{\mathrm{F}}}{\partial X} + (1-p)\frac{\partial U_{\mathrm{NF}}}{\partial X}}. \quad [10]$$

The new information provided by the 1993 flood alters a property owner's subjective assessment of the probability of flooding. As shown in equation [10], this term is multiplied by the ex ante risk discount to give the effect of information on property values. In the empirical application presented below, information is modeled as an interaction term that identifies sales of properties in the floodplain that also bracket the flood or occur postflood. The coefficient on this term gives the value of the change in the implicit price of risk attributable to the flood. This need not, however, mean that home prices move closer to some "true" cost of the risk. As mentioned earlier, much behavioral economics research indicates that individuals do not accurately assess low-probability risks. In particular, due to the availability heuristic, flood risk might be overassessed postflood, as the risk is now salient (Tversky and Kahneman 1973).

Most models of this type treat losses in the event of a flood as a known and fixed quantity and model learning as occurring only on the probability of a disaster. However, learning could occur on either parameter—that is, homeowners could update their assessment of probability or losses.[16] To allow for updating of potential losses after a flood, I model them as a function of information: $L(I)$. This makes the expression for EU:

$$EU = p(I,\ell)U_{\mathrm{F}}\{Y - H[p(I,\ell),\mathbf{Z},\ell] - L(I,\ell),\mathbf{Z}\} + [1 - p(I,\ell)]U_{\mathrm{NF}}\{Y - H[p(I,\ell),\mathbf{Z}],\mathbf{Z},\ell\}. \quad [11]$$

Maximizing this expression gives

$$\frac{\partial H}{\partial I} = \frac{\frac{\partial p}{\partial I}(U_{\mathrm{F}} - U_{\mathrm{NF}})}{p\frac{\partial U_{\mathrm{F}}}{\partial X} + (1-p)\frac{\partial U_{\mathrm{NF}}}{\partial X}} - \frac{p\frac{\partial L}{\partial I}}{p\frac{\partial U_{\mathrm{F}}}{\partial X} + (1-p)\frac{\partial U_{\mathrm{NF}}}{\partial X}}. \quad [12]$$

Equation [12] shows that the 1993 flood could have caused homeowners to update their estimates of the probability of a flood occurring or their assessment of expected losses, and both of these effects will be captured in the partial derivative of the hedonic function with respect to the new information. These effects will not be distinguishable, except in the case of a change in property prices for land that is not in a floodplain and faces a zero probability of a flood. In this case, the flood could not have altered p, only L.

V. DATA

For this paper, I merged St. Louis County property sales data for single-family, residential homes from the St. Louis County Revenue Department spanning the years 1979 to 2006, with a parcel-level GIS database from the St. Louis County Planning Department. The property records contain information on housing characteristics as well as sale date and price. I used the GIS

[16] For a discussion of updating losses versus probability in regards to pricing insurance, see Zeckhauser (1996).

database to identify the distance of properties to major roads and highways; the distance of properties to the nearest river and whether it was the Missouri, Mississippi, or a tributary; properties within a quarter mile of a park; the total area of each parcel; and school district, municipality, and census tract fixed effects. A GIS file of 4-ft contour lines was used to calculate the mean elevation of each property. After dropping properties for which data were missing, properties that sold for less than \$2,000 or more than \$10 million,[17] duplicates, properties that sold more than once on the same day for different prices (these are probably recording errors), and land-only sales (or those for which the sale type was missing), more than 430,000 sales were included in the data.

I used a GIS layer of FEMA's Q3 data to identify parcels in 100-year and 500-year floodplains. Q3 data are produced by FEMA by digitizing flood insurance rate maps and are for sale on the FEMA web site.[18] Due to the scale of the digitized flood maps, FEMA recommends that users apply a 250-foot buffer to the 100-year floodplain boundary. This is done here, although applying the buffer increases the number of properties within 100-year floodplains and creates a situation in which some properties fall within both 100-year and 500-year floodplains. The results were robust, however, to whether the double-coded properties were included and whether they were coded as being exclusively within the 100-year or 500-year floodplain or within both.

Table 1 provides definitions and summary statistics for each variable. I adjusted all sale prices to 2006 dollars using a housing price index specific to the St. Louis metropolitan statistical area.[19] The mean property value in constant dollars is \$125,794. Houses were built between 1790 and 2006, with a mean date of 1962. The mean area of a house is 1,670 ft^2; the mean area of an entire property is 13,800 ft^2 (about one-third of an acre). The number of stories in a house ranges from one to three, the number of rooms ranges from 1 to 94 with a mean of 6.6, and the total number of plumbing fixtures ranges from 1 to 46 with a mean of 8.4. The style fixed effects capture different architectural styles coded by the revenue department. St. Louis County includes 107 municipalities and unincorporated areas and 139 school districts. Of all sales in the database, 27,686 were for properties within 100-year floodplains, and 14,151 were for properties within 500-year floodplains.[20] Between 1993 and 2006, there was not a differential change in housing supply in and out of the floodplains, with the percentage of homes in 100-year floodplains increasing by 10.5% and the percentage outside 100-year floodplains increasing by 12.7%.

VI. EMPIRICAL RESULTS

Preflood Risk Discount

In this section, I present estimates of the extent to which flood risk was capitalized into property prices *before* the 1993 flood, using hedonic regressions on the pooled data for all sale dates prior to the flood. Economic theory does not provide guidance on the correct functional form, except that the first derivative of the price function be positive for "goods" and negative for "bads." Many authors have experimented

[17] The majority of sales less than \$2,000 had a sale price of zero, indicating that they were probably transfers of property and not true sales. Although any cutoff is somewhat arbitrary, results are robust to variations in the cutoff. Only 11 sales were over \$10 million, and results are robust to including these outliers.

[18] The estimated standard error for mapping the 100-year flood elevation is, on average nationwide, just under 25%, or an average depth of about 3 vertical feet (IFMRC 1994). In addition, there is some concern that FEMA's designations are not updated frequently enough. In rapidly developing areas, FEMA designations may underestimate the actual risk. The floodplain designations used here are from 1996.

[19] This was done using an index available for download from the Office of Federal Housing Enterprise Oversight. Although the index is for the entire metropolitan area, it should capture property value changes in the county fairly accurately.

[20] Data were not available on possible mitigation measures that homeowners in the floodplain could have taken, such as elevating the building or flood-proofing. It was thus not possible to examine the effect of such actions on property prices or to control for them in the regressions.

TABLE 1

VARIABLES AND SUMMARY STATISTICS

Variable	Description	Mean	Std. Dev.	Min.	Max.
Price	Property sale price adjusted to 2006 dollars	126,000	128,000	2,000	6,380,000
Year built	Year house built	1962	22.5	1790	2006
Near river	1 if property is within an eighth of a mile of the Mississippi or Missouri rivers	0.002	0.041	0	1
Square feet	Square footage of house	1,670	852	324	19,000
Property square feet	Square footage of property (thousands)	13.8	25.6	0.705	3,310
Quarter mile of a park	1 if property is within a quarter mile of a park	0.258	0.438	0	1
Distance to road	Distance to nearest major road (feet)	4,260	3,280	54.4	23,400
Stories	Number of stories	1.26	0.440	1	3
Rooms	Total number of rooms	6.61	1.75	1	94
Plumbing fixtures	Total number of plumbing fixtures	8.39	3.39	1	46
Tenure code	1 if owner occupied	0.876	0.329	0	1
School district fixed effects	School districts	—	—	0	139
Municipality fixed effects	Municipalities in St. Louis County	—	—	0	107
Style fixed effects	Code for style of house	—	—	1	12
Basement fixed effects	Code for presence and type of basement	—	—	1	4
Distance to river	Distance to nearest river (miles)	0.573	0.442	0	2.99
Tributary	1 if nearest river is a tributary	0.791	0.406	0	1
Elevation	Mean elevation in feet	565.1	61.53	396	892
100-year floodplain	1 if property is within 100-year floodplain and a 250-foot buffer	0.064	0.245	0	1
500-year floodplain	1 if property intersects a 500-year floodplain	0.033	0.178	0	1

with various functional forms (e.g., Halstead, Bouvier, and Hansen 1997). Most hedonic studies use the natural log of price as the dependent variable, as it is usually more normally distributed. This is the approach used here as well, although a Box-Cox transformation was also estimated (discussed below). The hedonic specification is, thus,

$$\ln(P_{\text{it}}) = \beta_0 + \sum_j \beta_j \mathbf{Z}_{itj} + \delta_1 100FP_i + \delta_2 500FP_i + \varepsilon_{it}, \qquad [13]$$

where i indexes each property and t indexes time.[21] As discussed above, I approximate flood risk using a dummy variable to indicate whether the property is within a 100-year or 500-year floodplain. Municipality, school district, and census tract fixed effects control for possible omitted variables that vary at any of those levels, such as property taxes or the crime rate. Price is in constant dollars, as already mentioned, and year fixed effects are included to capture any yearly shocks. I tested several transformations of the independent variables, and although the results were robust to all specifications, quadratic specifications of number of stories, total number of rooms, and total number of plumbing fixtures yielded the best fit to the data. The flood risk variables are not highly correlated with any of the other explanatory variables, minimizing multicollinearity concerns.

Results of the hedonic regression on the preflood data are given in Table 2. As the model in the previous section demonstrated, when estimating how property prices respond to flood risks, the floodplain variable could pick up other factors associated with being located within a floodplain,

[21] Although many previous studies have used a linearly additive specification on the right-hand side, this has no theoretical justification. The floodplain variables were interacted with several of the property variables, and they were either insignificant or the coefficients were sufficiently close to zero that I do not report them here. Some interaction terms of the structural characteristics of the house, such as the number of rooms and the number of plumbing fixtures, were significant, but their effects were small and did not change the coefficients on the flood variables; therefore I do not report these specifications.

TABLE 2

Preflood Effect of Flood Risk on Property Values

	I	II	III	IV	V
100-year floodplain	−0.0320*** (0.0107)	−0.0321*** (0.0099)	−0.0326*** (0.0100)	−0.0317*** (0.0107)	−0.0386*** (0.0107)
500-year floodplain	−0.0132 (0.0105)	−0.0131 (0.0099)	−0.0132 (0.0099)	−0.0129 (0.0105)	−0.0158 (0.0102)
Quarter-mile of Missouri or Mississippi	0.0462 (0.0418)	0.0459 (0.0423)	0.0406 (0.0403)	0.0463 (0.0418)	—
Distance to river in miles	—	0.0080 (0.0310)	−0.0183 (0.0491)	—	—
Distance to river in miles squared	—	−0.0108 (0.0191)	−0.0069 (0.0332)	—	—
Tributary	—	—	−0.0281 (0.0198)	—	—
Tributary*Distance to river in miles	—	—	0.0321 (0.0562)	—	—
Tributary*Distance to river squared	—	—	−0.0043 (0.0366)	—	—
Inverse distance to river	—	—	—	−0.0000** (0.000)	—
Eighth-mile band	—	—	—	—	0.0186** (0.0089)
Quarter-mile band	—	—	—	—	0.0051 (0.0070)
Over one mile band	—	—	—	—	0.0055 (0.0101)
Year built	0.0072*** (0.0004)	0.0072*** (0.0004)	0.0072*** (0.0004)	0.0072*** (0.0004)	0.0072*** (0.0004)
Square feet of house	0.0003*** (0.0000)	0.0003*** (0.0000)	0.0003*** (0.0000)	0.0003*** (0.0000)	0.0003*** (0.0000)
Property square feet in thousands	0.0015*** (0.0002)	0.0015*** (0.0002)	0.0015*** (0.0002)	0.0015*** (0.0002)	0.0015*** (0.0002)
Quarter mile of park	−0.0213*** (0.0074)	−0.0215*** (0.0074)	−0.0218*** (0.0074)	−0.0213*** (0.0074)	−0.0217*** (0.0074)
Inverse distance to road	−17.8274*** (3.8878)	−17.8762*** (3.8909)	−17.9853*** (3.8688)	−17.8383*** (3.8865)	−17.7338*** (3.9033)
Stories	0.6565*** (0.1691)	0.6571*** (0.1692)	0.6571*** (0.1693)	0.6565*** (0.1691)	0.6543*** (0.1690)
Stories squared	−0.2154*** (0.0565)	−0.2156*** (0.0565)	−0.2156*** (0.0565)	−0.2154*** (0.0565)	−0.2147*** (0.0564)
Rooms	0.0052 (0.0064)	0.0053 (0.0064)	0.0053 (0.0064)	0.0052 (0.0064)	0.0052 (0.0064)
Rooms squared	−0.0004 (0.0003)	−0.0004 (0.0003)	−0.0004 (0.0003)	−0.0004 (0.0003)	−0.0004 (0.0003)
Number of plumbing fixtures	0.0493*** (0.0047)	0.0493*** (0.0047)	0.0494*** (0.0047)	0.0493*** (0.0047)	0.0493*** (0.0047)
Plumbing fixtures squared	−0.0014*** (0.0002)	−0.0014*** (0.0002)	−0.0014*** (0.0002)	−0.0014*** (0.0002)	−0.0014*** (0.0002)
Tenure	0.0989*** (0.0110)	0.0989*** (0.0109)	0.0990*** (0.0109)	0.0989*** (0.0110)	0.0990*** (0.0110)
Fixed effects: Year, School district, Census tract, Municipality, Style, and Basement	Y	Y	Y	Y	Y
R^2	0.8289	0.8289	0.8289	0.8289	0.8289
N	153,185	153,185	153,185	153,185	153,185

Note: The dependent variable in all specifications is the natural log of the price in constant 2006 dollars. Errors are clustered by census tract. When errors are clustered in this way, more coefficients are being estimated than clusters, so it is not possible to test that all coefficients are simultaneously zero.

** Coefficient significant at the 0.05 level; *** coefficient significant at the 0.01 level.

preventing isolation of the risk discount. The five specifications in Table 2 present different ways of controlling for any impacts on property values of being located near a river, apart from flood risk. For all specifications, errors are clustered by census tract.[22] Specification I includes only a dummy variable for whether the property is within an quarter of a mile of the Mississippi River or the Missouri River. Specification II adds a variable that measures the distance from a property to the nearest river or creek and this distance squared. Specification III adds a dummy variable that has a value of one if the nearest river or creek is a tributary and zero if it is the Mississippi or Missouri. This variable is also interacted with the distance variables. Specification IV drops the previous distance variables and instead uses the inverse of the distance to the nearest river. Specification V groups properties into three distance bands based on whether the closest river is less than an eighth of a mile away, between an eighth and a quarter of a mile away, or more than one mile away. Several other specifications were tested in addition to those reported here.

Across all specifications, a robust, significant discount is associated with 100-year floodplain properties, with coefficients varying between −0.032 and −0.045. For a median-priced home, this is a discount of \$3,080 to \$3,754. To put this into perspective, this discount would equal the present value of annual flood insurance premium payments for a discount rate of 5% to 18%, depending on characteristics of the home that alter premiums.[23] No significant discount is associated with 500-year floodplain properties, although the estimates are as one would predict (negative and smaller than the 100-year floodplain coefficients), ranging from −0.013 to −0.016. If the individuals who choose to locate in floodplains are less risk averse than the general population or have lower subjective assessments of the risk (Yezer 2002), the implicit prices found here could be lower than if this type of sorting did not occur. If elevation of properties is included (not reported; available from the author), there is still a significant discount associated with 100-year floodplains. The effect is smaller, however, with coefficients ranging from −0.020 to −0.028. This is to be expected, since elevation and being in a floodplain are necessarily correlated.

Other estimated coefficients are as predicted. Property prices increase at a diminishing rate with the number of stories, number of rooms, and number of plumbing fixtures. Property prices are also higher for owner-occupied housing, more recently built homes, and greater square footage of the house or property. Prices are lower for properties near major roads and highways, perhaps because noise, pollution, and decreased aesthetics outweigh convenience benefits, and are also lower for properties near parks, although it is not clear why.

If the preflood data are disaggregated into those municipalities that are located on the Missouri or Mississippi rivers and those in the interior of the county, the findings are similar. A highly significant discount is associated with property in the 100-year floodplain; this discount is around 2.5% to 3% for municipalities on the major rivers and around 3.5% to 4.5% for 100-year floodplain properties in the interior of the county. This could be indicative of some degree of sorting based on risk preferences. No significant discount is associated with 500-year floodplains in either part of the county.

Serial correlation may be a problem in these regressions because some properties sold multiple times in the time period and I included all sales in the results presented in Table 2. I estimated an autoregressive

[22] Standard errors were also clustered by school district, municipality, and floodplain location. Coefficients on the floodplain variables continued to be significant.

[23] NFIP rates vary by flood zone and by characteristics of the house. The above estimates are for one- to four-family structures in a 100-year floodplain with one floor and no basement. If the structure is at base-flood elevation, for a median-priced home in St. Louis County, annual premiums would be \$542.50. If the property is elevated, rates can be reduced to \$180 per year for a median-priced home in St. Louis County.

AR(1) model and still found a significant discount of around 3% for properties in the 100-year floodplain and no statistically significant discount for 500-year floodplains. AR(1) correlation, however, may be a poor model for these data if the correlation is attributable to unique features of the property, such that the correlation does not decay over time. As a further robustness check, I used the average selling price for each property as the dependent variable. As another check, I randomly chose only one sale from each of the properties that sold more than once before the flood and ran the specifications on this reduced sample in which observations are independent (sample drawn multiple times). I found similar results in both cases.

To check the semilog specification, I ran a Box-Cox transformation on the dependent variable (Box and Cox 1964). Due to the difficulty in interpreting the coefficients, as well as the other disadvantages of Box-Cox estimation (Cassel and Mendelsohn 1985), I do not present the results here in table form. The Box-Cox estimation does, as a robustness check, though, provide a similar estimate of the effect on property prices of being located in a floodplain. For the median predicted sales price, being in a 100-year floodplain lowers property prices by \$3,034; this is close to the results found with the hedonic regression.[24]

Effect of the 1993 Flood

A DD model is often used to test for treatment effects and has been used previously to examine the information effects of a disaster (Bin and Polansky 2004). I present the results of a DD approach here first, although unobserved, time-invariant, omitted variables that covary with both floodplain properties and property prices could hinder estimation using the DD model. The preferred specification for estimating the effect of the 1993 flood on the floodplain property discount is, therefore, a repeat-sales model or a property fixed-effects model (others have preferred these approaches for property panel data, e.g., Mendelsohn et al. [1992]). I present these subsequently.

The DD specification for this analysis (using the semilog form again) is

$$\begin{aligned}\ln(P_{it}) = {} & \beta_0 + \sum_j \beta_j Z_{ij} + \delta_1 100FP_i + \delta_2 500FP_i \\ & + \delta_3 Postflood_{it} + \delta_4 100FP_i{*}Postflood_{it} \\ & + \delta_5 500FP_i{*}Postflood_{it} + \varepsilon_{it}\,. \end{aligned} \quad [14]$$

The variable *Postflood* is a dummy variable equal to one if the sale occurred after the 1993 flood.[25] The coefficients on the interaction terms estimate how the 1993 flood might have differentially impacted property sales that occurred postflood and in a floodplain. I assume that, had the flood not occurred, δ_4 and δ_5 would be zero.

The results of the DD estimation are presented in Table 3. No significant decline after the flood is associated with property within 100-year floodplains, but a significant decline of about 2% is associated with property located in 500-year floodplains. This is robust to whether elevation is or is not included in the model. It thus appears that little updating occurred in areas that had some prior knowledge of flood risk, as evidenced by the presence of a risk discount before 1993, but significant updating occurred where no prior capitalization of flood risk into property prices had taken place. If the flood caused updating of risks

[24] The transformation was not run on independent variables, as many are dummy variables, and because there is some evidence that quadratic Box-Cox functions do not perform well when there may be omitted variables (Cropper, Deck, and McConnell 1988). The Box-Cox transformation of the property price variable is given by $(\text{price}^\theta - 1)/\theta$ (when $\theta = 0$, it is the log of price). Maximum likelihood estimation found $\theta = 0.2493$ ($\theta = 1$ is a linear specification and $\theta = 0$ is a semilog specification) and a coefficient on the 100-year floodplain variable of -0.5691. This was for the inclusion of the independent variables in Specification I from Table 2.

[25] Flooding occurred at various locations in St. Louis County throughout July 1993. I considered a sale "postflood" if took place after August 1, 1993. I do not include sales between July 1, 1993, and August 1, 1993, in the estimation.

TABLE 3

EFFECT OF 1993 FLOOD ON POOLED DATA: DIFFERENCE-IN-DIFFERENCES MODEL

	I		II		III		IV		V	
Postflood*100-year floodplain	−0.0176	(0.0131)	−0.0176	(0.0131)	−0.0177	(0.0131)	−0.0176	(0.0131)	−0.0173	(0.0131)
Postflood*500-year floodplain	−0.0216*	(0.0126)	−0.0216*	(0.0126)	−0.0216*	(0.0126)	−0.0217*	(0.0126)	−0.0219*	(0.0125)
Postflood	−0.0600***	(0.0119)	−0.0600***	(0.0119)	−0.0601***	(0.0119)	−0.0600***	(0.0119)	−0.0599***	(0.0119)
100-year floodplain	−0.0247	(0.0168)	−0.0244	(0.0163)	−0.0248	(0.0163)	−0.0244	(0.0168)	−0.0300*	(0.0167)
500-year floodplain	0.0008	(0.0135)	0.0010	(0.0130)	0.0008	(0.0130)	0.0010	(0.0136)	−0.0013	(0.0133)
Quarter mile of Missouri or Mississippi	0.0414	(0.0325)	0.0419	(0.0331)	0.0360	(0.0305)	0.0415	(0.0324)		
Distance to river in miles			0.0091	(0.0318)	−0.0165	(0.0612)				
Distance to river in miles squared			−0.0094	(0.0174)	−0.0004	(0.0393)				
Tributary					−0.0313	(0.0212)				
Tributary*Distance to river in miles					0.0320	(0.0628)				
Tributary*Distance to river squared					−0.0108	(0.0393)				
Inverse distance to river							−0.0000*	(0.0000)		
Eighth-mile band									0.0148	(0.0104)
Quarter-mile band									0.0038	(0.0077)
Over one mile band									0.0028	(0.0099)
Structural, neighborhood, and locational characteristics	Y		Y		Y		Y		Y	
R^2	0.8185		0.8185		0.8185		0.8185		0.8185	
N	424,727		424,727		424,727		424,727		424,727	

Note: The dependent variable in all specifications is the natural log of the price in constant 2006 dollars. When errors are clustered in this way, more coefficients are being estimated than clusters, so it is not possible to test that all coefficients are simultaneously zero.

* Coefficient significant at the 0.10 level; *** coefficient significant at the 0.01 level.

that upset the market equilibrium, but transaction costs of moving were high, the coefficients estimated here will be lower than if homeowners could costlessly relocate after the flood.

It has been found that elevated homes in flood prone areas of New Orleans command a price premium and that this premium increased after Hurricane Katrina (McKenzie and Levendis 2008). To test for such postdisaster effects in St. Louis County, I interacted the elevation variable with the postflood and the 100-year floodplain variables (not reported; available from the author).[26] An interaction term of the 100-year floodplain, postflood, and elevation variables is never significant. The postflood, 500-year floodplain interaction variable remains significant in these specifications, and coefficients were similar to those reported in Table 3. If the postflood, floodplain interaction terms are removed from the regression and only the postflood, elevation, and their interaction variables included, the interaction term is significant at the 5% level, with a coefficient of 0.0003, suggesting perhaps a small increase in the value of elevation after the flood.

Repeat-sales model. A repeat-sales model (Palmquist 1982, 2005) is used to remove unobserved, time-invariant characteristics of a property. With B_t denoting the real estate price index, $\mathbf{Z}_i$ again giving the vector of property characteristics, and $\mathbf{C}_i$ giving the unobserved property-level characteristics, the price of property i in year t is given by

$$P_{it} = B_t g(\mathbf{Z}_i, \mathbf{C}_i) \exp(\gamma_1 FP_i{*}Postflood_{it}) \exp(\gamma_2 Postflood_{it}) \exp(\gamma_3 age_{it}) \exp(\varepsilon_{it}). \quad [15]$$

A similar equation can be written for the price of property in year s. Dividing the former by the latter and taking the natural log gives the repeat-sales model specification to be estimated. Assuming that structural, locational, and neighborhood characteristics of the properties are constant over time and that the effect of these variables on property prices is the same in each year, the function $g(\mathbf{Z}, \mathbf{C})$ cancels out.[27] With the function $g(\mathbf{Z}, \mathbf{C})$ dropping from the new equation, unobservables are no longer a concern. The depreciation of the house, as given by the age variable, and the price index are perfectly collinear, but estimating depreciation is not of interest here (nor is a price index), and the age variable can be eliminated. Note, also, that after the division, the interaction term identifying postflood sales of properties in the floodplain is equivalent to a term identifying sales in the floodplain that bracket the flood, and the postflood term is equivalent to a variable identifying sales that bracket the flood. This "bracket" variable is one for observations where the first sale is before the flood and the second sale is after the flood; it is zero otherwise. The ln B variables are the coefficients on dummy variables taking on the year of the sale (Palmquist 2005), so the repeat-sales model essentially becomes a first-differences specification of the DD model. The final regression equation is

$$\Delta \ln(P_{its}) = \beta_1 100FP_i{*}Bracket_{its} + \beta_2 500FP_i{*} Bracket_{its} + \beta_3 Bracket_{its} + + \beta_4 Year_t + \beta_5 Year_s + \Delta\varepsilon_{its}. \quad [16]$$

Although the repeat-sales model does address possible omitted variable problems, it is not without drawbacks. The sample is restricted to properties that sold more than once and is thus a nonrandom sample. It is assumed that the coefficients on time constant variables are stable over time. Finally, as discussed by Palmquist (2005), this approach assumes that real estate depreciates at a geometric rate, that risk has a linear effect on the natural log of

[26] Thank you to an anonymous referee for suggesting the need to consider the effects of elevation.

[27] This assumption that structural characteristics of the house remain the same over time is clearly tenuous, but data are not available on changes, and most characteristics are unlikely to be correlated with being located in a floodplain. I tested the assumption of a constant effect over time by including structural variables in a specification, but they were found to be exceedingly close to zero and/or highly insignificant.

TABLE 4
EFFECT OF 1993 FLOOD ON POOLED DATA:
REPEAT-SALES MODEL

Variable	I	
Bracket*100-year floodplain	−0.0133	(0.0114)
Bracket*500-year floodplain	−0.0262**	(0.0126)
Year of first sale	0.0122***	(0.0009)
Year of second sale	−0.0108***	(0.0009)
Bracket	−0.0095**	(0.0038)
R^2	0.0319	
N	202,933	

Note: The dependent variable is the change in the natural log of housing price. Errors are clustered by census tract.
** Coefficient significant at the 0.05 level; *** coefficient significant at the 0.01 level.

TABLE 5
EFFECT OF 1993 FLOOD ON POOLED DATA:
PROPERTY FIXED EFFECTS

Variable	I	
Postflood*100-year floodplain	−0.0136	(0.0135)
Postflood*500-year floodplain	−0.0257**	(0.0130)
Postflood	0.0180***	(0.0066)
Year fixed effects	Y	
Groups	222,546	
N	432,077	

Note: All data are time de-meaned. The dependent variable is the natural log of housing price. Errors are clustered by census tract.
** Coefficient significant at the 0.05 level; *** coefficient significant at the 0.01 level.

property price, and that the price index does not depend on property characteristics.

The results of the repeat-sales model are presented in Table 4.[28] As in the DD results, no statistically significant decline in price occurred for property in the 100-year floodplain, and property in 500-year floodplains had a statistically significant decline of 2.6%.[29] This model thus also suggests that a greater response to the flood occurred within 500-year floodplains than in 100-year floodplains. Including elevation interacted with the bracket variable or both the 100-year floodplain and the bracket variables did not change the results and was never significant.

Property fixed-effects model. Another way to control for unobserved, time-invariant characteristics of a property is to estimate a property fixed-effects model. The data are time de-meaned, which removes any unobserved characteristics that are fixed over time, and then an ordinary least squares model is estimated.[30] The results are presented in Table 5. Not surprisingly, they are essentially the same as those of the repeat-sales model in terms of magnitude and significance. The elevation terms were never significant when included and did not alter results.

Spatial Variation in the Information Effect of the 1993 Flood

One component of spatial variation in the information effect of the flood has already been examined: the differences between 100-year floodplains, 500-year floodplains, and nonfloodplain land. In this section, I investigate variations in the information effect across different areas of the county. I hypothesized that the 1993 flood would disproportionally affect property values in municipalities located along the Missouri and Mississippi rivers compared with properties in municipalities in the interior of the county, because the former experienced the bulk of flood-related costs. To test this hypothesis, I break the data into two groups: sales in municipalities located on the Missouri or Mississippi rivers and sales

[28] The fact that some properties in the dataset sold more than twice introduces correlation into the error terms. As a robustness check, I ran the repeat-sales model on multiple random samples with only one observation per property, and results were similar.

[29] I do not have parcel-level data on damage and repairs to property. If a property was rebuilt after the flood, such that the home is newer or has more amenities, this could contribute to finding no significant postflood decline in prices. If damage is done to the home that is not repaired before the sale, this would have the opposite effect. Because only a very small percentage of homes in St. Louis County were dramatically damaged in 1993, it is unlikely that changes to the house from damage or repairs are driving the results.

[30] Because of serial correlation in the repeat-sales model when there is more than one pair of sales per property, some authors have recommended the use of generalized least squares (GLS). As shown by Mendelsohn et al. (1992), the fixed-effects model on panel data gives the same result as the use of a GLS estimator on the first-differenced (repeat-sales) model.

in municipalities that did not share a border with one of these two rivers. I first run a DD model akin to equation [14] on each group. Two specifications for each group showing the range of results are presented in Table 6.

As seen earlier, a significant postflood decline of 2% to 5% is associated with 500-year floodplain properties, and no significant decline is associated with 100-year floodplains. The striking result of this estimation, however, is that all properties in municipalities located on the large rivers—within and outside of the floodplain—saw a significant drop in price of around 10.5%. When the data across the groups of municipalities are pooled and an interaction term is added to identify sales postflood that are located in the municipalities on the river, I find that prices of these properties were about 4.5% lower postflood than those of properties in the interior of the county. This result was significant at the 5% level. Controlling for elevation does not alter this result, and elevation interaction terms were not significant.

Repeat-sales model with spatial variation. To remove unobserved, time-invariant characteristics of a property, I again estimate a repeat-sales model with an interaction term added to identify sales that bracket the flood and that are located in municipalities on the rivers. The results are presented in Table 7. Property in 500-year floodplains declined postflood by about 3%, and I find no statistically significant decline for property in the 100-year floodplain. All property in municipalities located on the rivers fell sharply after the flood—in this estimation by about 8%—and this drop was highly significant. If elevation is interacted simultaneously with the bracket variable and the variable identifying municipalities on the major rivers, the coefficient is 0.0002 and is significant at the 5% level, suggesting perhaps a small differential response of the housing market to elevation after the flood in municipalities on the rivers.

Property fixed-effects model with spatial variation. The property fixed-effects model again echoes the findings of the repeat-sales model. Results are presented in Table 8. In this estimation, the postflood decline associated with property in municipalities located on one of the rivers is over 10%. This large drop for all properties in communities where the damage was greatest suggests that the costs of a flood, whether direct, indirect, or reputational, are borne by the community broadly and not just those properties in the floodplain. As in the fixed-effects model, an interaction term of elevation with sales that are postflood in municipalities on the major rivers is significant at the 5% level with a coefficient of 0.0002.

Temporal Variation in the Information Effect of the 1993 Flood

In addition to how the information effect of the flood varied spatially, the temporal duration of any information effect is also of interest. Declines in 100-year and 500-year floodplains were examined for each year by interacting the floodplain variables with year dummy variables in the property fixed-effects model. There was a large amount of noise, and the vast majority of the coefficients are statistically insignificant. Still, the year-by-year analysis does reinforce some findings of the paper. There is no observable change in the discount associated with 100-year floodplains after the flood as found in all the models. There does seem to be, however, a drop in the discount associated with 500-year floodplain properties compared to those in nonfloodplain areas. This is observable in Figure 4, which plots the coefficients of the year-floodplain interaction terms for the property fixed-effects model. The noise is high, but it appears the discount is diminishing somewhat over time.

VII. DISCUSSION

The results of the previous section show that knowledge of flood risk is present in 100-year floodplains before an extreme flood event. No statistically significant capitalization of flood risk into 500-year floodplain property prices was present

TABLE 6

DIFFERENCE-IN-DIFFERENCES BY MUNICIPALITY LOCATION

Variable	I		II		III		IV	
	Municipality Not on River		Municipality Not on River		Municipality on Missouri or Mississippi River		Municipality on Missouri or Mississippi River	
Postflood*100-year floodplain	−0.0277	(0.0231)	−0.0250	(0.0232)	0.0022	(0.0144)	0.0020	(0.0144)
Postflood*500-year floodplain	−0.0466*	(0.0251)	−0.0474*	(0.0251)	−0.0216*	(0.0130)	−0.0213	(0.0131)
Postflood	−0.0291	(0.0180)	−0.0294	(0.0180)	−0.1049***	(0.0108)	−0.1048***	(0.0108)
100-year floodplain	−0.0324	(0.0293)	−0.0477	(0.0302)	−0.0279**	(0.0135)	−0.0262*	(0.0137)
500-year floodplain	0.0079	(0.0216)	0.0024	(0.0217)	−0.0007	(0.0105)	−0.0006	(0.0103)
Quarter mile of river	—		—		0.0686	(0.0420)	—	
Distance to river in miles	0.2181***	(0.0595)	—		−0.0429	(0.0434)	—	
Distance to river in miles squared	−0.1289***	(0.0266)	—		0.0393	(0.0287)	—	
Eighth-mile band	—		−0.0260	(0.0230)	—		0.0046	(0.0129)
Quarter-mile band	—		−0.0394**	(0.0164)	—		0.0115	(0.0092)
Over one mile band	—		−0.0306	(0.0251)	—		0.0116	(0.0102)
Structural, neighborhood, and locational characteristics of property	Y		Y		Y		Y	
Fixed effects: School district, Municipality, Style, and Basement codes	Y		Y		Y		Y	
R^2	0.7977		0.7969		0.8168		0.8168	
N	229,017		229,017		195,710		195,710	

Note: The dependent variable in all specifications is the natural log of the price in constant 2006 dollars. Errors are clustered by census tract. When errors are clustered in this way, more coefficients are being estimated than clusters, so it is not possible to test that all coefficients are simultaneously zero.

* Coefficient significant at the 0.10 level; ** coefficient significant at the 0.05 level; *** coefficient significant at the 0.01 level.

TABLE 7
REPEAT-SALES ESTIMATES OF SPATIAL HETEROGENEITY

Variable	I
River-Muny*Bracket	−0.0782*** (0.0151)
Bracket*100-year floodplain	−0.0098 (0.0117)
Bracket*500-year floodplain	−0.0310** (0.0126)
Year of first sale	0.0122*** (0.0010)
Year of second sale	−0.0108*** (0.0009)
Bracket	0.0271*** (0.0083)
R^2	0.0359
N	202,933

Note: The dependent variable is the change in the natural log of housing price. Errors are clustered by municipality.
** Coefficient significant at the 0.05 level; *** coefficient significant at the 0.01 level.

before the flood, suggesting those property owners had little information on flood risks. Under the NFIP, home buyers must be informed that they are locating in a 100-year floodplain before they purchase the property. The capitalization of risk into prices in these areas and not 500-year floodplains before a disaster thus may suggest that the information component of the NFIP is working. While this paper cannot provide conclusive evidence, if this is the case, it provides some basis for extending risk information dissemination programs to 500-year floodplains. It could also be, however, that before the flood, homeowners in 500-year floodplains did not believe the risk to be large enough to require a risk discount on property prices.

After the 1993 flood, there was no significant change in the risk discount

TABLE 8
PROPERTY FIXED-EFFECTS ESTIMATES OF SPATIAL HETEROGENEITY

Variable	I
River-Muny*Postflood	−0.1043*** (0.0187)
100-year floodplain*Postflood	−0.0091 (0.0137)
500-year floodplain*Postflood	−0.0315** (0.0130)
Postflood	0.0643*** (0.0122)
Year fixed effects	Y
Groups	222,546
N	432,077

Note: The dependent variable is the change in the natural log of housing price. Errors are clustered by census tract.
** Coefficient significant at the 0.05 level; *** coefficient significant at the 0.01 level.

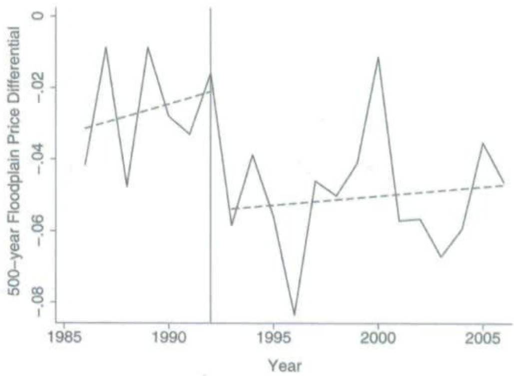

FIGURE 4
PRICE DISCOUNT ASSOCIATED WITH 500-YEAR FLOODPLAIN PROPERTIES (COEFFICIENTS FROM FIXED-EFFECTS MODEL WITH LINEAR FIT PRE- AND POSTFLOOD)

associated with 100-year floodplains. Perhaps homeowners in 100-year floodplains had information on flood risks before the flood, and the 1993 event did not provide much *new* information to move property prices. If an event confirms expectations, little updating will be done. This is termed an "anticipated disaster" by Yezer and Rubin (1987). However, since flood risks change over time and experts' risk estimates are uncertain, from a Bayesian perspective, we would have expected some updating of risk assessments in 100-year floodplains.

After the flood, prices in 500-year floodplains did decline. This could be due to those homeowners revising their estimate of the likelihood of being flooded because they previously were uninformed of the risk and are now aware, because they had previously underestimated the risk (perhaps due to out-of-date FEMA maps), or because the risk is salient postflood leading to an increase in perceived risk. The drop could also reflect an updating by homeowners on losses, as shown in the model presented in Section IV. If homeowners in 100-year floodplains did not alter their assessment of expected losses following a flood and those in 500-year floodplains did, this could explain differential the decline in 500-year floodplain prices.

The largest effect in magnitude of the 1993 flood was the decline in price for all property in communities located along the Missouri or Mississippi rivers. One explanation of this finding is that the flood imposed costs on all members of these communities, even those whose properties were outside of a floodplain. For example, in one municipality that suffered substantial flood damage, a major east-west highway was shut down and many businesses had to close. In several communities, municipal services, such as water and sewage treatment plants, were damaged by the flood (*St. Louis Post-Dispatch* 1993). The 1993 flood could have highlighted these costs to homeowners, causing them to update their assessments of losses and leading to a decline in prices for all properties in the affected communities.

Another explanation for the drop in property prices in the municipalities along the Missouri and Mississippi rivers is stigmatization, a type of negative externality in which property prices fall due to negative perceptions regarding something nearby. No risk is associated with the stigmatized area, but through information transmitted along many pathways (particularly the mass media), it develops a negative reputation because of nearby risks (Kasperson, Jhaveri, and Kasperson 2001). Many studies have addressed stigma surrounding contaminated or hazardous sites (e.g., Mundy 1992; Elliot-Jones 1996; Dale et al. 1999; McCluskey and Rausser 2003), but few have applied the concept of this neighborhood externality to other risks, such as flooding.

It is worth noting that it is not possible to determine whether homeowners' assessments of flood risk are moving closer to some true value of the risk postflood or not. This paper provides insight into the heterogeneity in how disasters alter risk perceptions but cannot make conclusions about whether the flood risk discounts in St. Louis County are "rational." Doing so would require many assumptions, not only about individuals, but also about a nonstationary risk and the heterogeneous damages that could be inflicted from a flood. This is an area for future work.

It is often suggested that homeowners may misunderstand what a 100-year flood or 500-year flood means and mistakenly assume that they are safer after a flood. Evidence regarding whether or to what extent this misunderstanding could have been present in St. Louis County is not conclusive. Properties within 100-year floodplains did not significantly decline in price after the flood. This could have been due to such a misunderstanding or could have occurred for other reasons discussed above. A drop in price occurred in 500-year floodplains, but it is impossible to test whether the decline would have been even larger if no homeowners had misunderstood the terminology.

Finally, it is not clear whether the observed change in property prices (or lack thereof) after the flood could be attributable to changing perceptions regarding federal relief or aid rather than changes in the perceived probability of a flood or losses should it occur. FEMA does not maintain county-level disaster obligation data to determine the magnitude of federal aid money given to homeowners. Information for the state of Missouri,[31] though, shows that FEMA spent close to a million dollars on temporary housing, just under half a million dollars on individual and family grants, and around \$84,000 on disaster unemployment assistance following the 1993 flood. Given that damages for the state are estimated at around \$3 billion (State Emergency Management Agency 2006), this is not a strikingly large amount, and the vast majority was for temporary housing. The Small Business Administration does provide loans for rebuilding, and some residents no doubt took advantage of these. It is possible that part of the response of property prices was due to the level of aid received, whether it was an over- or underestimation of what was expected. Previous investigations, though, suggest that most insured and uninsured individuals expect no federal aid in the event of a

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[31] Thanks to Ronald Charter for providing me with these data.

disaster (Kunreuther 1978), and the amount provided in 1993 does not seem substantial enough to cause a shift in perceptions large enough to move property prices.

VIII. CONCLUSION

Homeowners in St. Louis County—like those elsewhere in the country—are willing to pay for a reduction in the probability of a disaster. This allows their subjective assessments of flood risk to be inferred from the capitalization of risk in property prices. In St. Louis County, prior to the flood, a discount was associated with 100-year floodplains, suggesting knowledge of the risk. No discount was associated with 500-year floodplains. Perhaps intuitively, the flood led to the most updating where there had been little prior recognition of the risk: prices in 500-year floodplains declined by around 3%, whereas prices in 100-year floodplains were not affected. In addition, all prices—even those outside of the floodplain—declined in communities along the Missouri and Mississippi rivers, where flood damage was most severe. It is not possible to say whether the postflood updating in St. Louis County was "rational" without making many assumptions. A normative model of how homeowners should have updated their beliefs postflood, based on such assumptions, is also required to draw further policy recommendations. This is worthy of future research.

Still, it is clear from this study that risk information does influence homeowners. The discount associated with 100-year floodplains preflood may be a result of the information and insurance requirements of the NFIP, suggesting that government information provision programs may indeed have an impact on individual decision making.[32] If the government is the main source of risk information for homeowners, however, efforts must be made to improve the quality of this information. The FEMA-designated 100-year floodplains can be a severe underestimation of the "true" 100-year floodplain because they are not updated frequently enough to incorporate increased development, new data, or new estimation techniques (FEMA, Federal Insurance and Mitigation Division 2002). Perhaps some of the postflood drop in prices found in 500-year floodplains was attributable to homeowners realizing that the risk was greater than FEMA designations suggested.

This paper also highlights the effect of floods on those outside of the floodplain. The drop in prices for nonfloodplain properties suggests that floods may impose uninsurable costs on those whose properties are not flooded. These costs could include damages to infrastructure or the loss of myriad services on which governments should focus relief efforts. In addition, communities may become stigmatized after a disaster as "risk-prone"; such an effect would hurt homeowners who happen to live near a risky location, but whose properties are safe, and thus could be another cost of a disaster. The effects of stigma associated with natural disasters deserve further research. Many other impacts of the flood would also be worthy of investigation, such as induced changes in the risk management policies of local governments or, following Smith et al. (2006), changes in the composition of the communities most dramatically hit by the flood.

[32] An analysis of California's natural hazards disclosure law also suggests that government policy can improve the risk information homeowners receive (Troy and Romm 2004).

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